Changes in quality and maturity of 'Duke' and 'Brigitta' blueberries during fruit development: postharvest implications.

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Abstract

Fresh Chilean blueberries take in average 20-50 days to reach overseas markets, so a better knowledge of their postharvest behavior would help maintaining their quality for longer periods. Quality of highbush blueberries (*Vaccinium corymbosum* L., cv. 'Duke' and 'Brigitta') was assessed at six stages based on color: 100% green (100G), 75% green+25% pink (25P), 50% green+50% pink (50P), 25% green+75% pink-blue (75B), 90-100% blue (100B), 100% blue+5 extra days on plant (100B+5). Also, 75P, 100B and 100B+5 fruit were evaluated after storage at 2 °C for 45 days + 1d at 18 °C. Over berry maturation from 100G to 100B, color developed steadily while firmness and TA decreased. Respiration and ethylene production rates peaked early, at 25P and 50P, respectively, and were higher for 'Duke' than for 'Brigitta'. After harvest, cultivar- and maturity-related differences were found. 'Brigitta' fruit retained higher firmness and had lower weight loss than 'Duke'. In general, 100B+5 fruit were over-ripe and showed low quality. Additional physiological, morphological and biochemical studies for a wider range of cultivars will be needed.

1. Introduction

On a worldwide basis, blueberry (*Vaccinium corymbosum* L.) cultivation has grown significantly over the last two decades (Brazelton, 2009). Blueberries are climacteric fruit, which exhibit a raise on CO_2 and ethylene evolution during the middle stage of ripening (Windus et al., 1976; El-Agamy et al., 1982), so they are harvested at a post-climacteric stage, and will not improve in quality during handling and storage (NeSmith et al., 2002; MacLean and NeSmith, 2011). Blueberry fruit are extremely firm when green; soften substantially as they turn to red stages, but only slightly thereafter (Ballinger et al., 1973). The soluble solids content ranges from 7% in a green berry to about 15% in a fully ripe berry (Shutak et al., 1980), whereas fruit harvested as soon as they turn blue contain about 12% (Gough, 1984). Berries are considered ready to pick when they turn 100% blue, but since they do not ripen uniformly on a cluster (Gough, 1984; Lobos et al., 2014) growers usually wait for blue fruit to accumulate in the bushes between harvests. Whether fruit can be left on the bush without negatively impacting storage life is a mainly important question (Retamales and Hancock, 2012), since by this management, fruit with same color but different physiological maturity are harvested. Given that fresh Chilean blueberries are exported mainly by boat (Retamales et al., 2014) and fruit may take up to 50 days to reach final consumers, this heterogeneity may increase with longer storage periods affecting quality of the fruit upon arrival. It has been reported that ‘Elliott’ blueberries harvested at earlier stages of fruit ripening (immediately after achieving blue skin color) stored more satisfactorily than fruit harvested at more advanced stages (Hancock et al., 2008). On the other hand, other cultivars like ‘Liberty’ and ‘Aurora’ could be harvested later than usually done in commercial practice, without a loss in post-harvest storage life and an improvement in flavor (Lobos et al., 2014).

Given the above, there is the need to understand the pre- and postharvest behavior of different cultivars, in order to seek strategies to maintain their quality for longer periods. The main goal of this work was to study changes in quality and maturity during fruit development of ‘Duke’ and ‘Brigitta’ blueberries, and the postharvest behavior of fruit harvested at three different maturity stages and maintained 45 days under refrigerated storage**.**

2. Materials and methods

2.1. Fruit material and experimental setup

Highbush blueberries (*Vaccinium corymbosum* L., cv. ‘Duke’ and ‘Brigitta’) were picked from mature plants (8 and 9 years old, respectively) planted at a commercial field in Río Claro, Maule Region, Chile (35°15’35.16” South; 71°14’22.53” West). For fruit development assessments, samples were harvested every two to five days, and classified by visual grading into the following color categories: 100% green (100G); 75% green + 25% pink (25P); 50% green + 50% pink (50P); 25% pink +75% pink-blue (75B), 90-100% blue (100B) and 100% blue allowed to remain on the plant for 5 extra days (100B+5). In order to establish the last two stages, fruit clusters with similar characteristics (number and shape) and canopy position (superior third of the eastern side) were selected and labeled once 75B was reached. As these fruit reached 100% blue, one half thereof were harvested (100B), the other half remaining on the plant for extra 5 days (100B+5), in order to mimic the usual commercial practice. No visual differences in skin color could be perceived between 100B and 100B+5 fruit.

For each sampling date, three replicates of 25 fruit each were collected, in order to characterize maturity and quality at the different developmental stages. Additionally, four replications (125 g clamshells, 50 berries each) were harvested for 75B, 100B and 100B+5 fruit, placed in commercial cardboard boxes, and stored at 2 °C and 85-88% RH for 45 days. Fruit were evaluated for maturity and weight loss, after being kept 1d at 18 °C following removal from cold storage.

2.2. Maturity and quality assessments

For surface color, 25 individual blueberries were measured, at the equatorial zone, using a Minolta Chroma Meter (CR210, Osaka, Japan) calibrated with a white tile; lightness (L), hue angle (h°) and chroma (C*) are reported as proposed by McGuire (1992). Fruit weigh (g) and size (equatorial and polar diameter (mm)) were measured on the same 25 fruit with an electronic balance, and a digital caliper, respectively. Firmness (g mm^{-1}) was measured with a FirmTech 2 (BioWorks, Wamego, Kansas, USA) on four replicates of 25 fruit each. The equipment was set up at maximum and minimum compression forces of 200 g (1.96 N) and 15 g (0.15 N), respectively, and piston speed of 6 mm s^{-1}.

Soluble solids content (SSC) (%) was assessed on five berries per replicate with a digital refractometer (Atago, Pocket PAL-1, Tokyo, Japan). Titratable acidity (TA) (% citric acid) was determined in 10 mL of juice per replicate, after dilution with distilled water and titration with 0.1 N NaOH to pH 8.2.

For the evaluation of respiration rates (RR) (mL kg^{-1} h^{-1} CO_2), three fruit per replicate were placed for 2 h at 18 °C within a 28-mL sealed glass vial, and a Quantek 902P O_2/CO_2 analyzer (Quantek Instruments Inc., MA, USA) was used to measure CO_2 inside the vials. For the quantification of ethylene production (EP) (µL kg^{-1} h^{-1}), a gas sample (1 mL) was withdrawn with a syringe from the headspace volume, and injected onto a Shimadzu GC-2014 gas chromatograph equipped with a flame ionization detector and an alumina FID 80/100 mesh column. The injector, oven, and detector temperatures were set at 75 °C, 100 °C, and 170 °C, respectively, with helium as the carrier gas. Initial (harvest) and final (45+1) weight of each clamshell was recorded, for the estimation of weight loss (%) after storage.

2.3. Statistical analysis

Data were subjected to ANOVA, using a completely randomized design with maturity stage as the factor, separately for each cultivar. Mean separations ($P \leq 0.05$) were calculated (HSD test) using Statgraphics Centurion XVI (v.16.0.09).

3. Results and Discussion

'Duke' and 'Brigitta' fruit exhibited a raise on both RR and EP (Fig. 1), and as reported previously (Windus et al., 1976; Suzuki et al., 1997), differences were seen in the magnitude of the peaks and the stage of development at which they were reached. 'Brigitta' displayed a maximum RR and EP between 50P and 75B with mean values of 27.6 mL kg^{-1} h^{-1} CO_2 and 0.75 μL kg^{-1} h^{-1} ethylene, respectively. On the other hand, 'Duke' exhibited higher metabolic activity, in terms of both RR and EP; rise for EP of this cultivar (2.63 μL kg^{-1} h^{-1} ethylene) also occurred between 50P and 75B, but the peak in RR (94.2 mL kg^{-1} h^{-1} CO_2) was earlier (25P). According to Gough (1984), cultivars displaying higher respiration rates after harvest are least likely to keep well.

Fruit color (Table 1) as measured by colorimeter (L, chroma and hue angle) resulted in marked differences between 100G, 25P and 50P; but slight or none differences were found between 75B, 100B or 100B+5. Hue values are variable since changes in skin color change from green, to pink and blue; therefore, L and chroma would be better indicators of changes associated to berry development. Additionally no visual differentiation could be perceived between 100B and 100B+5.

The highest increase in fruit weight and diameter was observed during the first three stages of development (100G, 25P and 50P). Maximum fruit weight was reached on 'Duke' at B100 and B100+5 on 'Brigitta'. For both cultivars equator diameter increased up to B100 stage; polar diameter increased until H100+X on 'Duke' and 50P on 'Brigitta' (Table 2).

'Duke' and 'Brigitta' berries were very firm at 100G, but had lost 47% and 45% of initial firmness, respectively, when they reached 75B (considered as the first suitable harvest stage) (Table 3). The highest decline in firmness occurred between 100G and 25P for 'Duke' (30%), and between 50P and 75B for 'Brigitta' (34%), coincident with a peak in RR for 'Duke' and peaks in RR and EP for 'Brigitta'. A second important decrease on firmness was seen between 100B and 100B+5 (18.5% and 15.4% reduction for 'Duke' and 'Brigitta', respectively).

Additionally SSC augmented and TA decreased leading to increased values of SSC/TA ratio between 10.9 and 25.4 from 75B to 100B+5 stages (Table 3). Firmer fruit and SSC/TA ratios <18 have been associated to higher postharvest potential (Hanson et al., 1993; Galletta et al., 1971). In our study, values for 100B+5 fruit at harvest appear too extreme if long-distance markets are to be reached with acceptable quality.

Although 'Duke' fruit were firmer at harvest, firmness decline for this cultivar was high, since fruit lost 32%, 25% and 18% of initial firmness at 75B, 100B and 100B+5 stages, respectively, after cold storage (Table 4). For 'Brigitta' these decreases were 4%, 0.5% and 19%, respectively. Weight loss ranged from 10 to 21% on ‘Duke’ and from 6.4 to 9.8% on ‘Brigitta’; according to this, final firmness was negatively correlated with weight loss (R^2=0.61), explaining a better postharvest condition for ‘Brigitta’. Paniagua et al. (2013) reported similar results for blueberries stored at 4 °C and subjected to different airflow treatments.

4. Conclusions

- Duke’ displayed higher RR and EP than ‘Brigitta’ along fruit development and maturation, and resulted in lower postharvest quality.

- Although no visual or instrumental color differentiations could be perceived between 100B and 100B+5 stages at harvest, 100B+5 fruit consistently resulted in lower firmness and quality after storage.

- In order to avoid fruit heterogeneity that can lead to enhanced differences after longer storage periods, picking intervals should be narrower in cultivars that exhibit higher differences between these two maturity stages.

- Since main differences between cultivars were given by firmness and weight loss after storage, additional physiological, morphological and biochemical changes both on pre- and postharvest, need to be studied. Further emphasis should be given to the cuticle and its components.

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References

Ballinger, W.E., Kushman, I.J., and Hamann, D.D. (1973). Factors affecting the firmness of highbush blueberries. J. Am. Soc. Hortic. Sci. 6, 583-587

Brazelton, C. (2009). World Blueberry Acreage and Production Report. United States Highbush Blueberry Council-Industry Relations Committee, Folsom, California.

El-Agamy, S.Z.A., Aly, M., and Biggs, R.H. (1982). Fruit maturity as related to ethylene in 'Delite' blueberry. Proc. Fla. Stae Hort. Soc. 95, 245-246

Galletta, G.J., Ballinger, W.E., Monroe, R.J., and Kushman, L.J. (1971). Relationships between fruit acidity and soluble solids level of highbush blueberry clones and fruit keeping quality. J. Am. Soc. Hortic. Sci. 6, 758–762

Gough, R. (1984). The Highbush Blueberry and its Management. Food Products Press. Haworth Press Inc., 10 Alice Street, Binghamton, NY. pp.272

Hancock, J., Callow, P., Serçe, S., Hanson, E., and Beaudry, R. (2008). Effect of cultivar, controlled atmosphere storage, and fruit ripeness on the long-term storage of highbush blueberries. HortTechnology 18, 199-205

Hanson, E., Beggs, L., and Beaudry, R.M. (1993). Applying calcium chloride postharvest to improve highbush blueberry firmness. HortScience 28, 1033–1034

Lobos, G.A., Callow, P., and Hancock, J.F. (2014). The effect of delaying harvest date on fruit quality and storage of late highbush blueberry cultivars (Vaccinium corymbosum L.). Postharvest Biol. Technol. 87, 133–139. dx.doi.org/10.1016/j.postharvbio.2013.08.001

MacLean, D.D., and NeSmith, D.S. (2011). Rabbiteye blueberry postharvest fruit quality and stimulation of ethylene production by 1-methylcyclopropene. HortScience 46, 1278-1281

McGuire, R.G. (1992). Reporting of objective color measurements. HortScience27, 1254-1255

NeSmith, D.S., Prussia, S.E., Tetteh, M., and Krewer, G. (2002). Firmness losses of rabbiteye blueberries (*Vaccinium ashei* Reade) during harvesting and handling. Acta Hort. 574, 287–293

Paniagua, A.C., East, R., Hindmarsh, J.P., and Heyes, J.A. (2013). Moisture loss is the major cause of firmness change during postharvest storage of blueberry. Postharvest Biol. Technol. 79, 13–19.

Retamales, J.B., and Hancock, J.F. (2012). Blueberries. Crop Production Science in Horticulture. Series; no.21, CABI Publ. pp.323

Retamales, J.B., Palma, M.J., Morales, Y.A., Lobos, G.A., Moggia, C., and Mena, C.A. (2014). Blueberry production in Chile: current status and future developments. Rev. Bras. Frutic., Jaboticabal - SP 36, 58–67

Shutak, V.G., Gough, R.E., and Windus, N.D. (1980). The cultivated highbush blueberry: twenty years of research. Rhode Island Agricultural Experiment Station Bulletin 428

Suzuki, A., Kikuchi, T., Aoba, K. (1997). Changes in ethylene evolution, ACC content, ethylene forming enzyme activity and respiration in fruits of highbush blueberry. J. Japan. Soc. Hort. Sci 66(1), 23-27

Windus, N.D., Shutak, V.G., and Gough, R.E. (1976). CO2 and C2H4 evolution by highbush blueberry fruit. HortScience 11, 515-517

Table 1. Fruit color (L. Chroma and Hue) of 'Duke' and 'Brigitta' blueberries picked at six different stages of development[y]

Stage[z]	Duke			Brigitta		
	L[y]	Chroma[y]	Hue[y]	L[y]	Chroma[y]	Hue[y]
100G	62.6 a	33.6 a	121.5 c	62.9 a	21.2 a	104.7 b
25P	55.9 b	16.9 b	90.8 d	55.2 b	15.9 b	76.5 c
50P	43.9 c	12.1 c	19.0 e	39.6 c	12.4 c	12.8 d
75B	36.4 d	5.2 d	288.6 a	33.4 d	4.9 d	275.6 a
100B	35.0 d	4.6 d	266.3 b	34.4 d	5.7 d	267.3 a
100B+5	34.6 d	4.3 d	264.2 b	33.6 d	5.2 d	266.4 a
Significance (p)	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0007*	*0.0000*

[z]:100G (100% green fruit); 25P (75% green + 25% pink fruit); 50P (50% green + 50% pink fruit); 75B (25% green +75% pink-blue fruit); 100B (90-100% blue fruit); 100B+5(100%B fruit plus extra 5 days residing in the plant).
[y]Within a column, represent significant differences (Tukey's test, $p \leq 0.05$).

Table 2. Fruit size (weight and diameter) of 'Duke' and 'Brigitta' blueberries picked at six different stages of development[y]

Stage[z]	Duke			Brigitta		
	Fruit Weight (g)	Fruit diameter Equatorial (mm)	Fruit diameter Polar (mm)	Fruit Weight (g)	Fruit diameter Equatorial (mm)	Fruit diameter Polar (mm)
100G	0.56 d	7.01 e	4.9 e	0.85 e	12.2 d	8.7 c
25P	0.62 d	10.3 d	7.3 d	1.13 d	12.9 c	9.2 b
50P	1.21 c	14.1 c	9.4 c	1.55 c	14.8 b	10.8 a
75B	1.44 b	14.7 b	9.5 c	1.95 b	14.9 b	10.8 a
100B	1.72 a	15.3 a	10.1 b	2.21 b	15.2 a	11.4 a
100B+5	1.73 a	15.6 a	10.9 a	2.43 a	16.4 a	11.6 a
Significance (p)	*0.0038*	*0.0014*	*0.0000*	*0.0000*	*0.0017*	*0.0003*

[z]:100G (100% green fruit); 25P (75% green + 25% pink fruit); 50P (50% green + 50% pink fruit); 75B (25% green +75% pink-blue fruit); 100B (90-100% blue fruit); 100B+5(100%B fruit plus extra 5 days residing in the plant).
[y]Within a column, different letters represent significant differences (Tukey's test, $p \leq 0.05$).

Table 3. Fruit quality of 'Duke' and 'Brigitta' blueberries picked at six different stages of development[y]

Stage[z]	Duke				Brigitta			
	Firmness (g mm^{-1})	SSC (%)	TA (%)	SSC/TA	Firmness (g mm^{-1})	SSC (%)	TA (%)	SSC/TA
100G	334.1 a	6.0 d	2.90 a	2.8 e	358.4 a	6.8 d	2.80 a	2.4 e
25P	235.3 ab	8.6 cd	1.90 b	5.1 d	300.3 a	7.8 d	1.90 b	4.1d
50P	206.4 ab	9.3 c	1.80 b	8.3 cd	196.7 b	9.8 c	1.50 bc	6.5 c
75B	176.4 b	11.6 bc	1.00 c	11.5 c	162.7 c	12.3 b	1.10 c	10.9 b
100B	169.0 b	13.8 b	0.69 d	20.1 b	154.9 c	14.7 a	0.76 d	19.7 a
100B+5	137.8 c	16.4 a	0.65 d	25.4 a	131.1 d	14.7 a	0.64 d	23.5 a
Significance (p)	*0.0001*	*0.0000*	*0.0000*	*0.0020*	*0.0000*	*0.0000*	*0.0057*	*0.0013*

[z]:100G (100% green fruit); 25P (75% green + 25% pink fruit); 50P (50% green + 50% pink fruit); 75B (25% green +75% pink-blue fruit); 100B (90-100% blue fruit); 100B+5(100%B fruit plus extra 5 days residing in the plant).
[y]Within a column, different letters represent significant differences (Tukey's test, $p \leq 0.05$).

Table 4. Postharvest fruit quality of 'Duke' and 'Brigitta' blueberries picked at three different maturity stages and stored for 45 d at 2 ºC + 1 d at 18 ºC

Stage(z)	Duke					Brigitta				
	Firmness (g mm^{-1})	SSC (%)	TA (%)	SSC/TA	Weight loss (%)	Firmness (g mm^{-1})	SSC (%)	TA (%)	SSC/TA	Weight loss (%)
75B	119.5 ab	13.6 b	1.11 a	12.8 c	20.5 a	156.0 a	12.0 c	0.94 a	13.8 b	7.0 ab
100B	126.5 a	15.4 a	0.73 b	22.0 b	19.1 a	154.1 a	14.6 b	0.60 b	24.9 a	9.8 a
100B+5	112.8 b	16.3 a	0.51 c	34.2 a	10.0 b	105.6 b	15.9 a	0.60 b	27.8 a	6.4 b
Significance (*p*)	*0.0114*	*0.0001*	*0.0000*	*0.0000*	*0.0071*	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.064*

(z):100G (100% green fruit); 25P (75% green + 25% pink fruit); 50P (50% green + 50% pink fruit); 75B (25% green +75% pink-blue fruit); 100B (90-100% blue fruit); 100B+5(100%B fruit plus extra 5 days residing in the plant).

(y)Within a column, different letters represent significant differences (Tukey's test, $p \leq 0.05$).

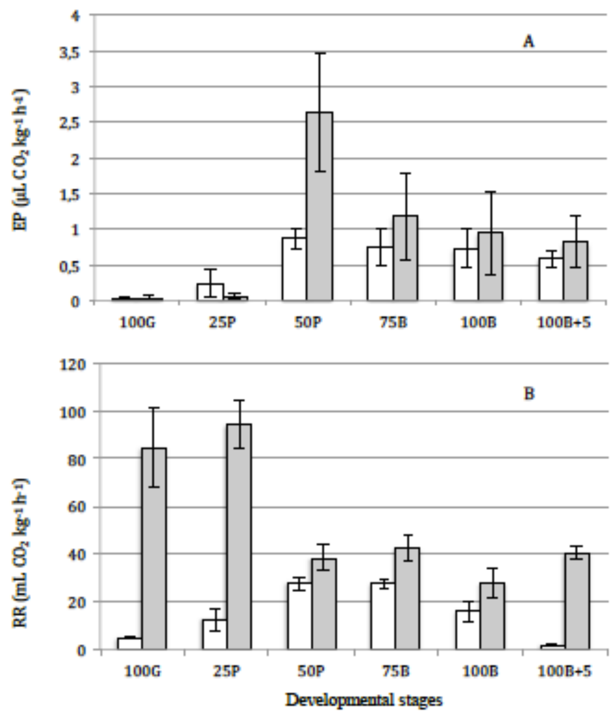

Figure 1. Evolution of (A) Ethylene production (EP) and (B) Respiration Rate (RR) of 'Duke' (grey bars) and 'Brigitta' blueberries (white bars) during different developmental stages: 100G (100% green fruit); 25P (75% green + 25% pink fruit); 50P (50% green + 50% pink fruit); 75B (25% green + 75% pink blue fruit); 100 B (90-100% blue fruit); 100B+5 (100%B fruit plus extra 5 days residing in the plant).